PARABOLIC SOLAR CONCENTRATOR MODULE

The present application is a continuation of PCT/IT02/00360.

The present invention relates to solar power plants for the production of energy and particularly to a panel or module of cylindric parabolic collectors, with a honeycomb structure, adapted to support thin mirrors, which concentrate the rays of sunlight on a tube, within which a fluid to be heated flows, for use in such plants.

Background of the Invention

Present systems for concentration of rays of sunlight are generally formed of curved glass mirrors having a 4mm thickness and cylindric-parabolic shape, with a 166cm spaced focus and a 576cm parabolic span, and which are supported by a reticular tube structure which has the strength necessary for withstanding deformation forces due to wind action. The mirror is self-supporting and is secured to an underlying structure by means of supports glued thereto.

Even if such a rectangular structure is sufficiently rigid and strong, it has, however, the drawback of being very heavy and requires very difficult assembling and alignment operations for the mirrors.

Another drawback of the above prior art lies in that the rigid mirrors, mounted on the reticular structure, need to be checked as to the convergence of the sunlight rays on the receiving tube within which the fluid to be heated flows, an operation which causes high installation costs.

The reflecting surfaces of the present plants can be stable for a long time, from both optical and mechanical points of view and can be easily cleaned, but in particular working conditions they are fragile. In fact, in some cases rupture stresses have resulted due to forces and vibrations caused by the wind and by interactions with the support structures.

For these reasons the glass panels arranged at the most exposed extremities of said structures have been strengthened by glass fibers to improve their mechanical characteristics. The present cost of the curved mirrors varies between 52 and $60/m², but in any case, additional costs for the assemblage and alignment of the mirrors in situ, must be considered, which may be estimated as $60/m². The mirrors should have excellent optical proprieties and need support structures for following the movement of the sun; all this being extremely expensive and establishes a need for an alternative system for reducing the costs of the collectors.

Brief D scription of th Invention

The main object of the present invention is to overcome the above problems and drawbacks by providing a solar energy concentrator module or panel having a parabolic shape with a honeycomb structure which supports thin glass mirrors, able to concentrate the rays of sunlight on a tube in which a fluid flows, which fluid is heated by the solar energy to a temperature suitable to be used for the production of solar energy. Preferably, the module is supported by a tubular element extending longitudinally, so as to support the panel honeycomb structure by means of suitable transverse fins and/or ribs.

Brief Description of the Drawings

The foregoing and other objects of the invention will be better understood from the following disclosure with reference to the enclosed drawings, which show by way of example two preferred embodiments of the present invention, wherein:

Figure 1 is a schematic view of the structure of a panel according to the invention;

Figure 2 is a representation of a parabolic transverse profile of the panel;

Figure 3 is a perspective view which schematically represents a first embodiment of the invention in which the panels with a honeycomb structure have a variable thickness;

Figure 4 is a perspective view which schematically shows a second embodiment of the invention in which the honeycomb panels have a constant thickness;

Figure 5 represents an example of ribs supporting the honeycomb panels;

Figure 6 shows a portion of a solar power plant with a plurality of panels aligned to form a solar concentrator; and

Figure 7 is a perspective view of a honeycomb panel having a constant thickness, in which the support ribs are formed by variable section fins.

Detailed Description of the Invention

As known, the reflecting panels and their support structures play an important role for determining the overall efficiency of solar power plants: such equipment should transfer the greatest quantity of energy to a receiving tube.

Towards this aim, the entire support structure should have low deformation levels caused by winds in working conditions. This is of particular concern, as in certain conditions the mirrors can behave as sails.

The parabolic shape of the panels has a wide surface, which can cause distortion due to the flexure and torsion of the entire structure. In any case, for avoiding excessive reductions to optical efficiency, deformation due to flexion and torsion moments should be less than ± 0.15° (with respect to the normal of the reflecting surface), whereas the induced tensions should not exceed the maximum tensile stresses of the material, and particularly of the mirrors. 0.15 degrees corresponds to the value of the maximum deviation of the sun's reflected rays, with respect to an ideal situation, in which there is no deformation of the parabola. In any case, the mirrors should be easily replaceable and adjustable in situ.

With respect to the above values, the present invention overcomes the problems characterizing known techniques, and incorporates the use of composite materials having a high stiffness and a low weight, such as honeycomb structures 1, on which are supported thin mirrors 2 having a thickness of about 1.1mm or slightly greater.

Such a construction may be achieved at low costs with the reflecting glass panels 2 having a small thickness and which are cold deformed.

The intrinsic rigidity of the (sandwich) panels allows the use of panels having a greater size with respect to the sizes of the mirrors as are presently employed. Further economical advantages are potentially possible by the reduction in materials and necessary support structures.

The sandwich panels P consist of a central layer or core 1 with a honeycomb structure, preferably of aluminium, on which two very thin layers (skins) 3, preferably of steel, are fastened, which improve the sturdiness properties and help maintain the shape of the entire panel.

High flexure strengths are assured by the two outer skins 3, which are subjected to tensive stresses. The central layer or core 1, formed with small honeycomb cells, should also have a high compression resistance to keep a constant distance between the skins.

The thermal expansion coefficient of the outer layers (skins) 3 are chosen to be similar to that of the core 1, for avoiding ruptures caused by differential elongations of the two materials. As it will be disclosed hereafter, steel has been found to be the most suitable material for skins, whereas aluminium, owing to its low weight, results in the most suitable material for the core 1.

The thin glass (mirror) 2 is fastened to one of the skins 3 of the concave surfaces of the panel P.

The novel curved honeycomb structure according to the invention (Figures 2 to 4 and 7), having reflecting surfaces 2 at the upper concave portion, improves sturdiness by avoiding dangerous deformations, which would normally hinder the use of less resistant thin and light mirrors. This constructive solution, besides conveniently offering a high sturdiness-weight ratio, also reduces the material and production costs.

The intrinsic sturdiness of the honeycomb structure facilitates the use of panels P having greater sizes, thus causing a further reduction of installation and regulation costs of the mirrors in situ, which in present existing plants equals the cost of a panel.

Moreover, the complexity of the present support structures is greatly reduced because the panels P, even if light, are self-supporting.

In the embodiment of Fig. 3, there is shown a panel P with a honeycomb structure and a varying thickness, which decreases starting from the parabola apex towards the longitudinal parabola edges.

The cylindrical support tube 4 has the function of transmitting to the entire structure and particularly to the reflecting parabolic panels the twisting moment of a motor MT. For simplifying the production process, the tube 4 could be constructed by folding a flat sheet into a closed polygonal shape, close to a circle, which is welded at its extremities.

As an alternative to this configuration, a second embodiment of the invention is provided (see Fig. 4), comprising curved honeycomb panels with a constant thickness, which are secured to the longitudinal support tube 4 by suitable support fins 5 integral therewith.

Preferably, each panel P has a length of about 3 meters and the aluminium honeycomb layer has a thickness of 25mm and is lined with 0.5mm thick skins of carbon steel.

The surfaces of the carbon steel skins are treated by an economical electro-galvanization process to protect the material from corrosion and increase the adhesion force of the mirrors. A waterproof material is applied to the mirrors by an adhesive layer to avoid an electro-chemical corrosion which can take place through contact of the silver-plated surfaces with water (an electrolyte). This is one of the main reasons for corrosion of the silver plating on the glass.

The thin mirror 2 is fastened to the panel by gluing with an epoxidic or acrylic glue and applying pressure by means of a curved spindle M to the concave support surface. The use of two steel sheets or skins 3 is important for assuring both the thermal stability and integrity of the mirror and maintaining good optical characteristics

over a wide temperature range. In fact, the thermal expansion coefficient of the steel ($10.8 - 12.6x10^{-6}$ m/m°C) is near to that of the glass ($5.6 - 12.6x10^{-6}$ m/m°C), whereas those of aluminium ($21.6x10^{-6}$ m/m°C) and plastic ($50x10^{-6}$ m/m°C) are much higher with respect to that of the glass.

The small difference between the expansion coefficients of the glass and steel minimizes the stresses and optical distortion caused by temperature changes, whereas the arrangement of the steel skins (and thus of the same material) on both the faces of the honeycomb layer advantageously minimizes curvature change. The modulus of elasticity of the steel (207.000 Mpa), higher than that of the glass (69.000Mpa) assures the maintenance of the initial curvature of the sandwich element, even if the ambient temperature changes.

Instead of the steel skins 3, skins of a lighter material, such as aluminium, could be employed but in such a case it is advisable to insert a glass fibre layer between the aluminium skin and thin reflecting glass 2, to accommodate the different thermal expansions of the materials.

The honeycomb panels P should be supported by a sufficiently rigid structure for avoiding deformation which could cause a reduction of the optical efficiency of the entire structure. In accordance with a particular feature of the invention, integration between the honeycomb panels and the support structure is provided: this solution simplifies the structure and facilitates its installation, thus attaining an improvement with respect to conventional structures having thick glass mirrors and a rectangular metal structure with hollow tubes).

A simple comparison of costs (per surface unit) between the conventional thick glass mirrors and the above disclosed thin mirrors 2 supported by honeycomb panels P does not fully emphasize the advantages of the invention, but when considering the cost reductions for the installed collector, whereby the structure and its installation costs weigh in almost equal proportions (receiving tube and motorization included), the advantages are evident.

As has been already mentioned, the structure supporting each module P, to which the reflecting surfaces 2 are fastened, is formed by a generally cylindrical tube 4, which preferably is provided with reinforcement fins or ribs which connect it to the panels 4 themselves (see Figs. 4, 5 and 7).

The entire support structure, schematically shown in Fig. 6, consists of a series of modules P of the above kind. In this example, the modules each have a length of 12 meters and a width of about 5.76m. Consequently, with 8, 4 or 2 modules it is possible

to have linear parabolic panels with a length of 100, 50 or 25 meters, actuated by a motor MT arranged at the half length or center which allows rotation of the parabolic element to follow the displacement of the sun during the day.

The criterion on which the limitation of the entire length of the parabolic element is based, originates from the need to limit both the deformations of the receiving tube caused by thermal expansion as well as the torsional deformations caused by wind action, without utilizing excessively heavy and complex support structures.

The supports at the ends of each module are not secured to allow thermal expansion. For minimizing the moment to be supplied by the motor for rotating the panel structure, the rotation axis extends through the center of gravity of the entire panel. It should be noted that the motor supplies a torque which should overcome friction forces and possible resistance couple due to the wind. The rotation moment is transmitted from the support tube 4 supporting the reflecting structure by means of the connection fins 5. The spacing or mutual distance between the fins 5 depends on the geometrical characteristics of the sandwich structure used for supporting the mirrors. In the case of panels with honeycomb core 1 of 2.5cm, the spacing between the fins can reach 3 meters.

To avoid the risk that the support tube 4 may be subjected to settlement or collapse in from the support fins, flanges or structural reinforcement elements can be inserted to increase the stiffness of the tube itself and provides a mechanical connection with the fins 5.

The follower system utilized with the invention, as known in the art, preferably includes a solar sensor and is provided with a feedback signal which assures exact alignment and concentration of the sun rays onto the receiving tube 6 with a precision of about 0.1°. The follower operation is monitored by a local computer assisted by a hardware unit assigned to this purpose. A control room may be provided with indicators of the working condition, alarms and diagnostics. Obviously, the control range for the alignment of the collector and possible corrections thereof are of particular importance.

The entire structure is preferably designed to operate in normal conditions at wind speeds up to between 40 and 60 Km/h and a maximum wind condition of 110 Km/h. At the limit velocity of 110 Km/h, the collector can be turned over and oriented to offer minimum resistance to the wind, forming an angle of 30° with respect to the horizontal position. For estimating the forces exerted by the wind on the glass panels a simulation by the FLUENT codex or simulation software, can be performed, whereas

for estimating the stresses and deformations acting on the materials the CASTEM codex has been used. The FLUENT software allows characterization of the pressure profile on the reflecting surface, as well as examination of instability phenomena caused by downstream vortexes on the reflecting surface, as well as low frequency oscillations which cause vibrations on the mirror surfaces. Analyses can also be performed at different inclination angles of the surface with respect to both the reflecting element and support structure.

A first preliminary test has been performed on a parabolic honeycomb panel, on which a uniform pressure of 500 N/m² (80 Km/h) has been exerted. In the specific case, the panel was formed with a core of 2.5cm and two skins of 0.5mm on the outer surfaces, with the features as set forth in the following table:

HONEYCOMB				SKINS	
Aluminum				Carbon steel	
Density			83 Kg/m^3	Density	8300 Kg/m^3
Cell sizes			6 mm	Young's Modulus	205 Gpa
Compression		E_C	1000 MPa	Poisson's Ratio	0.3
		Stress	4.6 MPa	Stress	285 Mpa
Plane	L direction	G_L	440 MPa	Thickness	0.5 mm
		Tension	2.4 MPa		
	W direction	G_W	220 MPa	Weight	4.15 Kg/m^2
		Tension	1.5 Mpa		

The test has been carried out with the following assumptions:

- The panel of 12 meters has the same characteristics along its extension: this means that all single panels are connected one with another and form a single module;
- The supports (fins on the lower surface) have a high stiffness;
- The panels have single honeycomb cells and shell shaped elements in the lower and upper wall of the surface layers (skins);
- The surface layers (skins) are formed of an isotrope material and the honeycomb is formed by a non-homogeneous material.

It is of interest to note that although from the numerical simulation (performed by supposing respectively 2, 3 and 4 support fins) there resulted in any case stresses lower than the acceptable maximum values, for having allowable deformations it is necessary to use panels with at least 3 fins: the use of four fins seems to be the most suitable choice. However, the number of fins depends on their structural characteristics and on materials used for attaining the necessary stiffness.

		Skins	*Honeycomb*		
Number of fins	Deformation (mm)	Stresses (Von Mises) (MPa)	Compression (MPa)	L Direction (MPa)	W Direction (MPa)
4	2,8	42	0,034	0,12	0,04
Limit Value	*8*	*285*	*4,6*	*2,4*	*1,5*

The present invention has been disclosed and shown in some preferred embodiments thereof, but one skilled in the art could perform modifications and attend to technically and/or functionally equivalent replacement without departing from the scope of the present invention.